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March 1986

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INTRODUCTION TO MARCH 1986 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the twelfth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the third quarter of calendar year 1985.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the telephone number of the individual to contact for more information on the topic; unless otherwise noted, this person is the first author. This issue also includes a calendar of Center conferences and workshops planned for fiscal year 1986, an announcement of recently issued standard reference materials, and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division (formerly the Semiconductor Materials and Processes and the Semiconductor Devices and Circuits Divisions) in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to CEEE Technical Progress Bulletin, National Bureau of Standards, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 921-3357.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 31.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division.

NIST
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1986

TABLE OF CONTENTS

INTRODUCTION . . . . . inside front cover

SEMICONDUCTOR TECHNOLOGY PROGRAM

Analysis Techniques 2

Dimensional Metrology 2

Integrated Circuit Test Structures 3

Process and Device Modeling 4

Packaging 6

Other Semiconductor Metrology Topics 6

SIGNALS AND SYSTEMS METROLOGY PROGRAM

FAST SIGNAL ACQUISITION, PROCESSING, & TRANSMISSION 7

Waveform Metrology 7

Cryoelectronic Metrology 9

Antenna Metrology 11

Noise Metrology 13

Microwave Metrology 14

Laser Metrology 15

Optical Fiber Metrology 16

Other Fast Signal Topics 17

ELECTRICAL SYSTEMS 20

Power Systems Metrology 20

Pulse Power Metrology 22

Superconductors 22

Magnetic Materials and Measurements 25

Other Electrical Systems Topics 25

ELECTROMAGNETIC INTERFERENCE 25

1986 CEEE CALENDAR 29

RECENTLY ISSUED STANDARD REFERENCE MATERIALS 30

SPONSOR LIST 31

KEY CONTACTS IN CENTER, CENTER ORGANIZATION . . . . . back cover

SEMICONDUCTOR TECHNOLOGY PROGRAM

Analysis Techniques

Released for Publication

Baghdadi, A., Gladden, W.K., and Flach, D.R., **Nonlinear Effects of Digitizer Errors in FT-IR Spectroscopy.**

This paper is an investigation of the effects of errors in the analog-to-digital converter (ADC) of a Fourier transform infrared (FT-IR) spectrometer on the photometric accuracy of that spectrometer. The effect of ADC errors on the spectrum after Fourier transformation is calculated analytically for monochromatic, two-line and wide square-band emission spectra. Numerical modeling is used to extend the analysis to absorption spectra, and to include the effects of noise on the amplitude of absorbance bands. These analyses showed that ADC errors can generate artifacts throughout the spectrum, although the largest effects occur at sharp spectral features. Errors as large as 8% in the amplitude of absorbance bands can be produced by ADC errors of one least significant bit (LSB), in a 15-bit ADC. These results were confirmed qualitatively by measuring the net height of the oxygen vibrational band in silicon at 1107 cm^{-1} using four different ADC circuit boards in the same FT-IR spectrometer. At the highest signal levels, the boards disagreed by as much as 4%, even though the static transfer characteristics of the ADC boards (which were measured in a separate experiment) exhibited errors of less than ±2 LSBs.
[Contact: (301) 921-3786]

Dimensional Metrology[1]

Released for Publication

Kirk, C.P., and Nyyssonen, D., **Modeling the Optical Microscope Images of Thick Layers for the Purpose of Linewidth Measurement**, Proc. SPIE - The International Society for Optical Engineering, Vol. 538, pp. 179-187 [Conference, Santa Clara, California, March 13-14, 1985].

A monochromatic, waveguide model is presented which can predict the optical microscope images of thick layer objects including multi-layer structures, sloping, curved and undercut edges, granular structures such as polysilicon and asymmetric objects. The model is used to investigate the effects of line structure on the optical image and good agreement with experimentally obtained optical image profiles is demonstrated. Implementation of the model is described by way of example and the measurements involved in the different stages of manufacturing an MOS device are discussed.
[Contact: Robert D. Larrabee (301) 921-3625]

Nyyssonen, D., **A Practical Method for Edge Detection and Focusing for Linewidth Measurements on Wafers**, Proc. SPIE - The International Society for Optical Engineering, Vol. 538, pp. 172-178 [Conference, Santa Clara, California, March 13-14, 1985].

Lack of precision and accuracy of in-process critical dimension (CD) measurements of linewidth continues to be a serious problem at micrometer and submicrometer dimensions. Even with highly repeatable optical linewidth measurement systems, variable "offsets" or errors have been shown to occur with changes in process variables such as thickness of the patterned layer and sublayers and changes in the indices of refraction of the materials. All of these variations result in changes in the optical phase difference which occurs on reflection at the line edge and, therefore, results in changes in the structure of the optical image. Although an accurate coherent optical edge detection method has been

[1] This work was transferred to the Center for Manufacturing Engineering, Precision Engineering Division, at the beginning of Fiscal Year 1986 (Oct. 1, 1985).

Dimensional Metrology, cont'd.

developed, it requires accurate knowledge of the phase difference, which is not always possible in CD measurements. This paper proposes a new edge detection and focusing method, based on image theory, which can be adapted to most optical microscope-based measurement systems. It does not require knowledge of the phase difference at the line edge. The accuracy of this criterion is compared to the more widely used criteria of the minimum and 50% threshold and it is concluded that, when the phase difference is unknown and varies with normal processing, the new dual threshold method is the superior method.
[Contact: Robert D. Larrabee (301) 921-3625]

Integrated Circuit Test Structures

Released for Publication

Linholm, L.W., Cresswell, M.W., Coleman, E.S., and Partlow, W.D., **Design, Fabrication, and Testing of an Interconnect Test Structure for Evaluating VLSI Processes**, to be published in the 1985 Digest of Papers, Government Microcircuit Applications Conference, Orlando, Florida, November 5-7, 1985.

This paper describes a systematic approach to the comparative experimental evaluation of alternative sub-micron lithographic methods using microelectronic test structures. Measurements are presented for both polysilicon and aluminum lines with design geometries of 0.6 to 2.0 μm. These structures provide unambiguous results which can be used as a tool to improve the control and performance of VLSI devices.
[Contact: (301) 921-3801]

Radack, D.J., Yao, C.T., Linholm, L.W., Galloway, K.F., and Lin, H.C., **Comparison of Microelectronic Test Structures for Propagation Delay Measurements**, to be published in the Microelectronics Journal.

This paper presents a comparison of the ring oscillator, the inverter chain, and the delayed Johnson counter for measurement of the propagation delay of an inverter. The paper describes design considerations that will improve the precision and accuracy of the measurement. Additionally, the paper describes modifications to the delayed Johnson counter which allow timing comparisons to be performed on-chip.
[Contact: (301) 921-3801]

Schafft, H.A., **Standards for Electromigration Testing**, to be published in the Proceedings of the 1984 Wafer Reliability Assessment Workshop, Lake Tahoe, California, September 30-October 3, 1984.

This is an edited transcript of a talk given at the 1984 Wafer Reliability Assessment Workshop which includes questions, comments, and responses. The talk described plans for an interlaboratory experiment and other work that is intended to lead to an improved way for characterizing metallizations for electromigration. The talk outlined the steps of the interlaboratory experiment, discussed some of the design features of the test structures to be used, described the electromigration test chip, and mentioned some of the experiments that will be performed.
[Contact: (301) 921-3801]

Recently Published

Yen, D., Glendinning, W. B., and Linholm, L. W., **An Electrical Test Structure for Proximity Effects Measurement and Correction**, J. Electrochem. Soc., Vol. 132, No. 7, pp. 1726-1729 (July 1985).

This paper describes the design of a test structure and electrical test method for estimating the magnitude of proximity effects in electron-beam lithography. The test structure consists of a van der Pauw cross resistor for measuring sheet resistance, a bridge resistor for measuring electrical linewidth, and

IC Test Structures, cont'd.

a second bridge resistor simulating a close line- space environment for measuring electrical linewidth where proximity exposure effects from nearby patterns may be encountered. In this experiment, test structures were delineated in aluminum on silicon wafers using electron-beam exposure and wet chemical etching. Electrical measurements from these test structures are compared to optical measurements to verify the measurement method. In addition, results from the test structures are used to estimate the Gaussian parameters for the Gaussian model commonly used for proximity corrections.
[Contact: Loren W. Linholm (301) 921-3801]

Process and Device Modeling

Released for Publication

Dutta, P.K., and Wilson, C.L., **Calculation of Surface Potential and Electron Density Near Threshold for a Nonuniformly Doped Channel VDMOS Power Device.**

The surface potential, ψ_s, and electron density, n, along the nonuniformly doped channel of a power DMOS transistor are computed, using both a charge-sheet model and a two-dimensional model. Results are obtained for gate voltages in the range of 2.0 V to 4.0 V. The threshold of the device is about 3.0 V. Nonuniformity in the channel doping of the transistor requires a point-by-point calculation of ψ_s and n, as one progresses from the drain end to the source end. The results indicate that near threshold, a simple charge-sheet model can adequately approximate the rigorous two-dimensional analysis for calculation of ψ_s and n. The charge-sheet model calculation is approximately 800 times faster than the two-dimensional model calculation.
[Contact: (301) 921-3621]

Hefner, A.R., and Blackburn, D.L., **An Analytical Model of the Power Insulated Gate Bipolar Transistor.**

A basic equivalent circuit model for the power Insulated Gate Bipolar Transistor (IGBT) is developed. It is shown that the IGBT behaves as a wide-base bipolar transistor which is supplied base current by a MOSFET. Analytical expressions are developed, using ambipolar transport theory, for the electron and hole current densities and for the excess carrier concentrations in the thick, lightly doped epitaxial layer of the IGBT. Expressions are also developed for the steady-state anode to cathode voltage drop and the transient anode current waveform, which consists of an initial rapid fall followed by a slowly decaying portion. The value of β_{tran} (the ratio of the value of the current immediately after the initial rapid fall to the magnitude of the fall) is shown to depend on the anode loading conditions and to be different from the steady-state common emitter current gain of the wide-base bipolar transistor. Measured and predicted values of β_{tran} for constant anode voltage load conditions as functions of anode current and neutral base width agree to within experimental error, in the current range where ambipolar transport theory is valid. Device parameters extracted from the measured β_{tran}-versus-anode-current characteristics are used to predict the on-state voltage versus current characteristics, which agree to within a few millivolts with the measured results.
[Contact: (301) 921-3621]

Lowney, J.R., **Impurity Bands and Band Tailing in Moderately Doped Silicon.**

The density of states of the valence and conduction bands in silicon has been calculated at room temperature for dopant densities near the transition between the existence of a distinct impurity band and its coalescence with the continuum band to form a band tail. The dopant densities for the three cases considered are: 1) 1.5×10^{18} cm^{-3} acceptors; 2) 6.2×10^{18} cm^{-3} acceptors;

Process & Device Modeling, cont'd.

and 3) 1.2×10^{19} cm^{-3} donors compensated by 6.2×10^{18} acceptors. The calculation is based on multiple-scattering theory with the self-energy calculated self-consistently to all orders of the interaction. The results show a small but significant amount of effective band-gap narrowing.
[Contact: (301) 921-3786]

Roitman, P., Wilson, C.L., Blue, J.L., and Galloway, K.F., **Measurements for Accurate MOS Transistor Simulation,** to be published in the Proceedings of the 3rd International Workshop on the Physics of Semiconductor Devices, Delhi, India, November 27-December 2, 1985.

Measurements and input data required for accurate numerical simulation of MOS transistor characteristics are described. Techniques for determining dopant atom distributions, geometric parameters, and carrier mobility in the channel are discussed. The results are used to simulate the electrical characteristics of self-aligned, silicon-gate, n-channel MOSFETs with phosphorus source-drains having channel lengths of 0.80 μm, 1.83 μm, and 8.17 μm. It is possible to model the drain current for all of the transistors studied without adjustable parameters. If sufficiently accurate parameters are available, the characteristics of submicron transistors can be predicted with ±5% accuracy.
[Contact: (301) 921-3621]

Wilson, C.L., **Using Silicon Device Modeling Techniques for GaAs Devices,** to be published in the Technical Digest, 1985 International Electron Devices Meeting, Washington, DC, December 1-4, 1985.

Numerical models have been developed for Si MOSFETs which achieve high accuracy and retain numerical stability and physical flexibility. The methods used in these models can be applied to GaAs MESFETs to yield a computer model which retains the accuracy and robust numerical properties of two-dimensional Si MOSFET models yet retains most of the physical detail of Monte Carlo simulation. Two significant differences between this model and previous models result. First, by incorporating intraband scattering directly, high field regions of the device are seen to be dominated by alternate regions in which conduction by central valley and satellite valley electrons dominate. Second, the two-dimensional field shape in the part of the transistor between the gate and the drain is critical in calculating the intraband scattering and in determining the average effective mobility.
[Contact: (301) 921-3621]

Wilson, C.L., and Russell, T.J., **Two-Dimensional Modeling of Channel Hot-Electron Effects in Silicon MOSFETs,** to be published in the Technical Digest, 1985 International Electron Devices Meeting, Washington, DC, December 1-4, 1985.

Earlier models have successfully modeled currents associated with device degradation due to channel hot electrons. In this work, a high accuracy two-dimensional model of a silicon MOSFET is combined with a model of the SiO_2-Si interface which includes both (1) the energy dependence of the interface traps within the silicon bandgap and (2) the positional dependence of the oxide charge and the interface traps along the channel of the transistor. This model allows the effects of channel hot electrons on the subthreshold, linear, and saturation regions after injection of the device to be modeled without introducing free parameters.
[Contact: (301) 921-3621]

Recently Published

Wilson, C.L., Roitman, P., and Blue, J.L., **High Accuracy Physical Modeling of Submicron MOSFETs,** IEEE Transactions on Electron Devices, Vol. ED-32, No. 7, pp. 1246-1258 (July 1985).

Process & Device Modeling, cont'd.

Using the data obtained from the measurements described in this work, it is possible to model the drain current for all of the transistors studied with no adjustable parameters. Transistors with 0.81-μm channel length differ in model input from those with 8.17-μm channel length only in the length of the polysilicon gate. The accuracy of the simulation is maintained over the subthreshold, triode, and saturation regions and is comparable for all channel lengths.
[Contact: (301) 921-3621]

Packaging

Released for Publication

Harman, G.G., **Acoustic-Emission Tests for Microelectronic Tape Automated Bonding (TAB)**, to be published in the ASNT (American Society for Nondestructive Testing) Nondestructive Testing Handbook, Vol. 5, Acoustic Emission Testing.

An acoustic-emission (AE) test method and equipment for tape automated bonding (TAB) integrity have been developed. The system consists of a precision testing machine that simultaneously applies a clamping force on the semiconductor chip and a lifting force on the electrical interconnecting leads. Acoustic-emission signals are transmitted through a waveguide to the detector. The system also permanently forms (raises) the leads, which is a normal requirement for TAB devices. Large acoustic-emission signals occur when a lead breaks, a bump lifts, or a weld crack propagates. Appropriate AE signal processing is also discussed.
[Contact: (301) 921-3625]

Harman, G.G., **An AE-Monitored Thermal Shock Test for Hybrid Microcircuit Packages**, to be published in the ASNT (American Society for Nondestructive Testing) Nondestructive Testing Handbook, Vol. 5, Acoustic Emission Testing.

An acoustic-emission-monitored test for hybrid microcircuit package integrity was developed. It consists of a hot stage operating at 400°C, a special water-cooled acoustic-emission detector mount, and appropriate signal recording equipment. In use, the detector is coupled to the back of a hybrid package and both are set on the hot stage for approximately 30 s. Any acoustic-emission signals indicate thermal excursion damage to the glass-metal seals. The acoustic-emission signals were correlated with both room temperature and 125°C leak tests of the packages.
[Contact: (301) 921-3625]

Recently Published

Oettinger, F.F., **Thermal Measurements of VLSI Packages - A Critical Overview**, in book, Abstracts of the IEEE/NBS VLSI Packaging Workshop, Gaithersburg, Maryland, September 9-11, 1985, pp. 26-29.

Techniques to thermally characterize ceramic and plastic VLSI packages are discussed. Computer simulations and both direct and indirect thermal evaluation techniques are highlighted. Limitations and strengths of the various techniques are identified.
[Contact: (301) 921-3541]

Other Semiconductor Metrology

Released for Publication

Stern, E.A., Ma, Y., and Bouldin, C.E., **The Local Structure at Mn Sites in Icosahedral Mn-Al Quasicrystals.**

Extended x-ray absorption fine structure (EXAFS) measurements have been made at the Mn K-edge of quasicrystalline and crystalline forms of an Al_6Mn alloy. Two different quasicrystalline Mn sites are discerned to be populated in the ratio of τ within experimental error. The more populous site is similar to that in the crystal but with bond angle distortions and elimination of an unusually short Al-Mn bond, while the

Other Semiconductor Metrology, cont'd.

other site has additional bond stretching distortions. The EXAFS measurements together with density measurements indicate that the volume per Mn-site is independent of type of site, suggesting that the quasicrystal is not a Penrose lattice.
[Contact: Charles E. Bouldin (301) 921-3786]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Released for Publication

Bell, B.A., Editor, **Proceedings of the Seminar on Digital Methods in Waveform Metrology**, to be published as NBS Special Publication 707.

Modern electronic instrumentation metrology in the low-frequency regime (dc-10 MHz) was discussed in lecture talks and papers presented at NBS, Gaithersburg, MD, on October 18-19, 1983. The seminar program was organized into four main session topics, as outlined in the Seminar Agenda.

This special publication contains complete papers on the subjects presented at the seminar, providing more of the technical details. For the sessions on Precision Waveform Synthesis, Precision Waveform Sampling, and Data Converter Characterization, six formal papers are given describing the hardware and software techniques used for developing NBS laboratory standards and apparatus for testing ac sources and voltmeters, phase angle meters, transient waveform recorders, wideband wattmeters, and digital-to-analog and analog-to-digital converters. For the informal session on Instrumentation Metrology, three subsequent papers have been written for publication which are included for completeness in the Appendices.
[Contact: (301) 921-2727]

Laug, O.B., Stenbakken, G.N., and Leedy, T.F., **Electrical Performance Tests for Audio Distortion Analyzers**, to be published as NBSIR 85-3269.

Electrical performance test procedures for audio distortion analyzers were developed by the National Bureau of Standards for the U.S. Army Communications-Electronics Command. The report provides detailed, step-by-step test procedures that are based on specifications supplied by the Army for purposes of evaluating audio distortion analyzer bid samples. Examples of data sheets and tables are also provided for recording interim and final results.

The report discusses the philosophy of each measurement procedure with a view toward providing an understanding of the basic metrology required to perform the measurements. In addition, the sources of measurement error are discussed. The primary applications and basic principles of modern audio distortion analyzers are also presented.
[Contact: (301) 921-2727]

Nahman, N.S., **Software Correction of Measured Pulse Data,** to be published in the Proceedings at the NATO Advanced Study Institute, Castelvecchio, Lucca, Italy, July 9-23, 1983.

The fundamental concern in the software correction of measured pulse waveform data is the solution of an ill-posed deconvolution problem which arises when one (or both) of the known waveforms is (are) corrupted by errors due to interference, noise, instrumentation drift, etc. The variables concerned are related to each other by the convolution integral. When one of the integrand functions is unknown while the other two functions are known, the convolution equation becomes an integral equation for the unknown waveform. Solution of an ill-posed deconvolution problem is obtained by signal processing or filtering and at most yields an estimate for the unknown waveform. The objective of this discussion is to bring out the

Waveform Metrology, cont'd.

ideas of ill-posedness and to give examples of applications to pulse measurement problems which require deconvolution, i.e., the removal (correction) of pulse source effects and/or measurement system effects as encountered in signal pulse waveform measurements and system impulse response measurements.
[Contact: (303) 497-5167]

Souders, T.M., and Stenbakken, G.N., **Modeling and Test Point Selection for Data Converter Testing**, to be published in the Proceedings of the 1985 IEEE International Test Conference, Philadelphia, Pennsylvania, November 18-22, 1985.

Methods for generating efficient testing strategies for data converters are presented. Linear modeling techniques based on circuit analysis and empirical test data are included, as well as algorithms for selecting optimal test points. Using these tools, converter errors can be accurately estimated for all code states from a relatively small number of measurements.
[Contact: (301) 921-2727]

Stenbakken, G.N., Souders, T.M., Lechner, J.A., and Boggs, P.T., **Efficient Calibration Strategies for Linear, Time Invariant Systems**, to be published in the Proceedings of Autotestcon '85, IEEE International Automatic Testing Conference, Uniondale, New York, October 22-24, 1985.

An efficient strategy for accurately characterizing the frequency response of linear, time invariant systems is presented. The approach, based on circuit modeling, test point selection, and parameter estimation, optimizes calibration confidence with respect to test effort. The analytic tools and methodology needed for designing the strategy are included, together with experimental results. The approach can be particularly beneficial in volume testing of devices such as amplifiers, attenuators and filters, or systems whose frequency response is dominated by such devices.
[Contact: (301) 921-2727]

Recently Published

Gans, W.L., **Picosecond Pulse Measurements at NBS,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 142-144.

The primary system used at NBS, Boulder to measure fast (picosecond to nanosecond regime), repetitive, electrical pulse parameters consists essentially of a wideband (dc-18 GHz) sampling oscilloscope interfaced to a minicomputer. This paper describes the techniques employed at NBS to reduce the effects of two major sources of pulse measurement error. These two sources are the distortions caused by the sampling head circuitry and by sample timing jitter. The techniques employed are based on the deconvolution methods of Tikhonov.
[Contact: (303) 497-3538]

Kuffel, J., Malewski, R., van Heeswijk, R., and Lawton, R.A., **Dynamic Performance of Digital Recorders Used for Monitoring High Voltage Impulse Tests**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 211-215.

Frequency and time domain characteristics of digital transient recorders (in short, digitizers) are discussed in order to establish the requirements on digitizers used for high voltage testing. Results of an experimental study performed on a 200-MHz, 8-bit digitizer (Tektronix 7612D) are presented and related to the design features of this instrument. The inherent design characteristics and their influence on the digitizer dynamic performance are analyzed in view of simulation of the digitizer through a computer model.
[Contact: Robert A. Lawton (303) 497-3339]

Waveform Metrology, cont'd.

Larsen, N.T., Vecchia, D.F., and Sugar, G.R., **VOR Calibration Services,** NBS Technical Note 1069 (April 1985).

The National Bureau of Standards has designed, constructed, and evaluated a standard for the support of very-high-frequency omnidirectional range (VOR) air navigation aids. The standard consists of two instruments: (1) a digital waveform signal generator for the composite VOR audio waveform, and (2) a standard phasemeter based on time series analysis of this waveform. Experimental results, a statistical analysis of them, and the listings of principal software are included.
[Contact: (303) 497-3711]

Lawton, R.A., **Pulse Waveform Standards for Electro-Optics,** Picosecond Electronics and Optoelectronics, Proceedings of the Topical Meeting, Lake Tahoe, Nevada, March 13-15, 1985, G.A. Mourou, D.M. Bloom and C.-H. Lee, Eds., (Springer-Verlag, Berlin), pp. 205-206.

This paper describes the development of reference waveform generators for transfer of NBS pulse measurement accuracy to an emerging class of electro-optic samplers having picosecond and subpicosecond time-resolution capabilities. A comb generator appears to be a promising candidate: it is commercially available and physically compact, it exhibits good signal-to-noise ratio, and the waveform duration covering the most significant parts of the waveform is commensurate with one scan of the sampler used.
[Contact: (303) 497-3339]

Lawton, R.A., **Status Report: Transient Waveform Recorder Standard,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 154-155.

The origin and activities of the Waveform Measurement and Analysis Technical Committee of the Instrumentation and Measurement Society of the IEEE are described. Responding to the recent availability of several digital waveform recorders, the committee is developing a performance standard for waveform recorders. The participants on the committee are identified, and the current state of development of a draft standard is given.
[Contact: (303) 497-3339]

Leedy, T.F., and Bell, B.A., **Automatic Test Equipment Calibration/Performance Verification Evaluation and Research Program (JLC/DoD Subtask 30702),** NBSIR 84-2978 (December 1984).

This work describes an experimental approach to verify the performance of selected third-generation automatic test systems. As part of an ongoing project, this work builds on previous research in methods to characterize the accuracy of test systems measuring ac and dc voltages. This report describes the methods used to characterize an ac voltage source covering a voltage range of approximately 225 mV to 2.8 V rms over a frequency range of 50 kHz to 10 MHz. In addition, the characterization of a precision phase angle generator, designed and built at NBS, is described. Finally, the measurement results obtained with an automatic test system, using a new software operating system and the ac, dc, and phase angle transport standards, are discussed in detail.
[Contact: (301) 921-2727]

Cryoelectronic Metrology

Released for Publication

Hamilton, C.A., Kautz, R.L., Steiner, R.L., and Lloyd, F.L., **A Practical Josephson Voltage Standard at One Volt.**

A series array of 1484 pairs of Josephson junctions biased by microwaves at 72 GHz is demonstrated to provide stable quantized voltages at the 1 volt level.
[Contact: (303) 497-3740]

Cryoelectronic Metrology, cont'd.

Recently Published

Hamilton, C.A., Lloyd, F.L., and Kautz, R.L., **Superconducting A/D Converter Using Latching Comparators**, IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 197-199 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

This paper describes the design and performance of a six-bit analog-to-digital (A/D) converter using fast edge latching comparators. Simulations predicting conversion times of 100 ps and 100-MHz signal bandwidth are verified experimentally. The addition of a superconducting track/hold circuit in front of the A/D converter is expected to substantially improve the signal bandwidth.
[Contact: (303) 497-3740]

Kautz, R.L., **Chaos and Thermal Noise in the RF-Biased Josephson Junction**, J. Applied Physics, Vol. 58, No. 1, pp. 424-440 (1 July 1985).

The effect of thermal noise on chaotic behavior in the rf-biased Josephson junction is studied through digital simulations. In instances for which chaotic behavior occurs in the noise-free system, it is found that the dynamics of the system are almost unchanged by the addition of thermal noise unless the level of thermal noise exceeds that of the chaotic state. In instances for which the only stable states of the noise-free system are periodic solutions, small amounts of thermal noise can induce the junction to hop between two different dynamical states, producing a low-frequency noise level much higher than that of the thermal noise. Such noise-induced hopping can occur either between two periodic solutions or between a periodic solution and a metastable chaotic solution. When a metastable chaotic state is involved, temperatures somewhat higher than those which produce hopping can destabilize the periodic solution to the point where the system spends virtually all of its time in the metastable chaotic state, creating noise-induced chaos. The similarities between chaotic behavior at zero temperature and noise-induced chaos are sufficiently strong that it may be difficult to distinguish the two cases experimentally.
[Contact: (303) 497-3391]

McDonald, D.G., and Frederick, N.V., **Amplification by a Voltage Locked Array of Josephson Junctions**, Applied Physics Letters, Vol. 47, No. 5, pp. 530-532 (1 September 1985).

We have studied a new type of Josephson junction amplifier which is based on a two-junction array; the junctions are mutually phase locked at the Josephson self-oscillation frequency. With this frequency at 82 GHz, the voltages of the junctions remain equal (locked) for a bias current range as large as 60% of the critical current. Over a much smaller bias range, with an applied signal frequency of 1 kHz, a small-signal power gain of 19 dB was measured, accompanied by a negative resistance input impedance. This performance is consistent with a quasi-static theory of the amplifier.
[Contact: (303) 497-5113]

McGrath, W.R., Raisanen, A.V., Richards, P.L., Harris, R.E., and Lloyd, F.L., **Accurate Noise Measurements of Superconducting Quasiparticle Array Mixers**, IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 212-215 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

We have constructed a 30-40 GHz test apparatus which allows us to measure the noise temperatures of superconductor-insulator-superconductor (SIS) mixers with an accuracy of better than ±1 K. This is a factor of six improvement over earlier measurements. The most accurate measurement made thus far of a mixer

Cryoelectronic Metrology, cont'd.

which uses a single Pb-alloy junction yielded T_M = 9.2 ± 0.9 K; and mixer gain: C_M = 0.240 ± 0.005. In addition, SIS mixers employing arrays of N = 1, 5, 10, 25, and 50 tunnel junctions in series have been tested. The input power required to saturate the array mixers was found to increase as N^2 and the gain and noise temperatures of the array mixers were independent of N.
[Contact: Richard E. Harris (303) 497-3776]

Muhlfelder, B., Beall, J.A., Cromar, M.W., Ono, R.H., and Johnson, W.W., **Well Coupled, Low Noise, dc SQUIDS**, IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 427-429 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

We have designed, fabricated, and tested a Double Transformer (DT) coupled dc SQUID (Superconducting Quantum Interference Device) with low noise, an input inductance of 1 μH, and a smooth input-output characteristic. A transmission line model is presented to explain a resonance in the input-output characteristic of early versions of this device. Guided by the results of numerical simulations, a new version of this device has been built and tested. Experimental results are presented that show that the resonance can be moved to a higher voltage by reducing the area of the SQUID loop. The voltage-external flux characteristic of some of these new devices agrees to within 10% with computer simulations. The minimum detectable energy per unit bandwidth (MDE) referred to the SQUID loop is 10 h, where h is Planck's constant. Computer simulations indicate an MDE of 6 h.
[Contact: (303) 497-3597]

Ono, R.H., Beall, J.A., and Harris, R.E., **Fabrication of a Miniaturized DCL OR Gate**, IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 846-849 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

Using niobium edge junctions and electron-beam lithography (EBL), we have made direct-coupled-logic (DCL) OR gates with 1-μm minimum linewidths. The gate cell, containing an isolator and a buffer section, fits into an area of approximately 25 by 30 μm^2.

Our computer simulations show that these gates can have switching times of less than 10 ps. We have simulated the DCL circuit with several values of the most space-consuming element, an inductor. This paper describes the results of these simulations and presents a detailed description of the 7-level fabrication process. The mix of optical and electron-beam lithography used relies heavily on an inexpensive, yet powerful, circuit layout program.
[Contact: (303) 497-3762]

Antenna Metrology

Released for Publication

Lewis, R.L., **Spherical-Wave Source-Scattering-Matrix Analysis of Coupled Antennas; A General System Two-Port Solution.**

Expressions are given for the coupling between two antennas in terms of each antenna's spherical-wave source-scattering matrix. A comparison with the "classical" scattering matrix representation is given in sufficient detail to permit conversion back and forth between the source-scattering matrix and the classical scattering matrix. The paper concludes with expressions for the transmission formulas, showing two different expressions corresponding to reversing the direction of propagation. However, if both antennas are reciprocal with equal characteristic waveguide impedances, then the two-port scattering matrix is a symmetric matrix.
[Contact: (303) 497-5196]

Antenna Metrology, cont'd.

Lewis, R.L., and Wittmann, R.C., **Improved Spherical and Hemispherical Scanning Algorithms.**

A probe-corrected spherical-scanning algorithm has been developed which is applicable when the antenna under test radiates negligibly into its rear hemisphere. Compared to an efficient version of the best previously published full-sphere scanning algorithm, it is found that our hemispherical scanning algorithm is over three and a half times more efficient. Improvements have also been made to full-sphere scanning, with the result that our new spherical scanning algorithm is twice as efficient as the best previous full-sphere algorithm. We also show that our new formulations constitute an exact inversion of the band-limited spherical-coordinate representation of the received signal (i.e., no aliasing errors are introduced).
[Contact: (303) 497-5196]

Newell, A.C., and Repjar, A.G., **Development of Near-Field Test Procedures for Communication Satellite Antennas, Phase I, Part 1,** to be published as NBSIR 85-3031.

The purpose of this program is to define and further develop the capabilities of near-field antenna test techniques, specifically for the requirements associated with the development and verification testing of reconfigurable, multibeam, frequency reuse, commercial satellite antennas. Phase I, Part 1 gives a general survey, definition, and description of near-field and compact range measurement methods as they apply to satellite antenna systems testing. Each of these methods is evaluated to determine how well it meets the measurement requirements. Included for each technique is a summary of the measurement method, discussions on probe correction and data processing, measurement hardware considerations, a results-available section, and measurement accuracy and range certification considerations. The basis for the choice of the best measurement technique is established with the planar near-field measurement method receiving the best score for the directive antennas considered. As a result, further study will focus on this technique and will be reported on subsequently. A detailed presentation of planar near-field measurements theory is presented in Appendix A.
[Contact: (303) 497-3743]

Recently Published

Hill, D.A., **Out-of-Band Response of Reflector Antennas,** NBSIR 85-3021 (April 1985).

The response of reflector antennas to out-of-band frequencies has been analyzed using physical optics. A simple approximate expression has been obtained for the effective aperture, and this expression yields both the receiving pattern and the frequency dependence on the on-axis gain. The theory has been compared with published out-of-band measurements, and the pattern agreement is good, but the measured gain falls below the theory. This discrepancy is caused by mismatch loss in the coax-to-waveguide adapter.
[Contact: (303) 497-3472]

Hill, D.A., and Koepke, G.H., **A Near-Field Array of Yagi-Uda Antennas for Electromagnetic Susceptibility Testing,** NBS Technical Note 1082 (July 1985).

In electromagnetic susceptibility testing of electronic equipment, the ideal incident field is a plane wave. To approximate this condition, a seven-element array of Yagi-Uda antennas has been constructed and tested at a frequency of 500 MHz. The element weightings are determined by a near-field synthesis technique which optimizes the uniformity of the field throughout a rectangular test volume in the near field of the array. The amplitude and phase of the electric field have been measured throughout the test volume with

Antenna Metrology, cont'd.

a short dipole probe, and the agreement with the theory is excellent.
[Contact: (303) 497-3472]

Muth, L.A., **A Theory of Mutual Impedances and Multiple Reflections in an N-Element Array Environment,** NBS Technical Note 1078 (February 1985).

A general theoretical approach is formulated to describe the complex electromagnetic environment of an N-element array. The theory reveals the element-to-element interactions and multiple reflections within the array. From the formulation, it is found that the interaction between an excited element and an open-circuited element can be viewed as the sum of terms describing all possible signal paths within the array environment which start from the radiating element and terminate on the element under observation. Within all paths except the most direct one, multiple reflections between subgroups of elements take place. The resulting solution is highly structured and recursive and is discussed in detail in the text. Illustrative examples are provided to facilitate understanding of these ideas.
[Contact: (303) 497-3603]

Wyss, J.C., and Sheeran, S.T., **A Practical Optical Modulator and Link for Antennas,** J. Lightwave Technology, Vol. LT-3, No. 2, pp. 316-321 (April 1985).

This paper describes a practical application of a technique for coupling an antenna to a receiver using a passive fiber-optic link. This technique should avoid pickup and electromagnetic perturbations normally associated with the use of electrically conductive cables. Laser light (632.8 nm) is modulated at the antenna by an electrooptic lithium-tantalate crystal and is then transmitted with a fiber-optic cable to the receiver electronics. Using an avalanche photodiode, the amplitude-modulated optical signal is converted to an electrical signal. The crystal is mounted directly on an antenna without amplifiers or other electrically powered components. Using a broad-band antenna with fields generated in an anechoic chamber and a standard TEM cell, the frequency response as measured dropped 3 dB per 1.0 GHz from 100 MHz to at least 2.0 GHz, with a signal-to-noise ratio of 5 dB with a 1.0-V/m field and a 1.0-kHz bandwidth. A dynamic range of at least 60 dB is shown.
[Contact: Charles K. S. Miller (303) 497-3131]

Noise Metrology

Recently Published

Daywitt, W.C., **A Derivation for the Noise Temperature of a Horn-Type Noise Standard,** Metrologia, Vol. 21, pp. 127-133 (1985) [previously published as Appendix A, NBS Technical Note 1071, December 1983].

Noise sources consisting of an electromagnetic horn aimed at an absorbing material have been in use for many years. A satisfactory derivation of the noise temperature for such a configuration has been missing, however, preventing the use of this horn-type noise source as a primary reference standard. The derivation described in this paper models the various noise emitters within the source well enough to provide an accurate estimate of the noise temperature and a complete error analysis.
[Contact: (303) 497-3720]

Daywitt, W.C., **Broadband Noise Source Applications,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 165-166.

Accurate noise characterization of amplifiers and communication systems requires the use of thermal noise standards. This note is a brief review of the use of such standards as a basis for the measurement of effective input noise

Noise Metrology, cont'd.

temperature and the G/T of a satellite earth terminal receiving system.
[Contact: (303) 497-3720]

Perera, S., **Noise Temperature Measurements at the National Bureau of Standards,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 159-160.

Thermal noise presents the ultimate limitation in the reception and detection of low-level electromagnetic signals. This paper briefly reviews the physics of thermal noise, devices that generate noise, and measurement methods to characterize noise sources.
[Contact: (303) 497-3546]

Reeve, G.R., and Miller, C.K.S., **Current NBS Metrology Capabilities and Limitations at Millimeter Wave Frequencies,** Proceedings of the 1985 Measurement Science Conference, Santa Clara, California, January 17-18, 1985, pp. 296-314.

The National Bureau of Standards (NBS) establishes national artifact standards and provides a metrology base for U.S. industry and technology. In the millimeter wave frequency spectrum, NBS has not established all of the required metrology to meet the needs of industry or government for this technology. It is the intent of this paper to describe the technical demands of responding to the challenges of millimeter-wave technology. A description of the current capabilities that exist at NBS is given for those parameters and frequencies where measurement services exist. Where novel standards have been developed, such as the 94-GHz thermal noise standard, the physical basis for the standard is described to indicate the changes from lower frequency designs and the challenges that had to be overcome. Limitations in services and in concepts of standards for providing those services are described to indicate the degree of research that must be undertaken to satisfy future industrial needs in this evolving technology.
[Contact: (303) 497-3557]

Microwave Metrology

Released for Publication

Wilson, P.F., and Chang, D.C., **Mode Coupling by a Longitudinal Slot for a Class of Planar Waveguiding Structures: Part I - Theory, Part II - Applications.**

Coupling between two parallel-plate waveguides is investigated. Mutual excitation is due to a longitudinal slot in a common plate. The introduction of reflecting boundaries parallel to the slot allows one to model a number of planar waveguiding structures featuring a common coupling mechanism. Part I of this paper details the analysis of the basic slot scattering problem based on the singular integral equation method. If one assumes that the slot is small, then closed-form algebraic modal equations follow. These modal equations are well adapted to numerical parametric studies.

Part II of this paper presents specific examples of the above approach along with numerical results. Examples include a rectangular coaxial transmission line, broadwall-coupled rectangular waveguides, coupled microstrips, and coupled microstrip and rectangular waveguide.
[Contact: (303) 497-3842]

Recently Published

Holt, D.R., and Hoer, C.A., **Estimation of True Power Ratios in Six-Port Network Analyzers Using Diode Detectors,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 140-141.

A model for detector nonlinearity is included in the determination of six-

Optical Fiber Metrology, cont'd.

A method using mode transfer matrices to characterize step index fiber components and predict Local Area Network (LAN) power budget is presented. The results show this method is well adapted to describing modal power distribution variations.
[Contact: Robert L. Gallawa (303) 497-3761]

Shao, Y., Alvarez, R., Weimer, C., and Gallawa, R.L., **Pulse Spectrum Analysis Method Measuring Fiber Bandwidth**, to be published in Proc. SPIE - The International Society for Optical Engineering, 559 [Conference, San Diego, CA, August 18-23, 1985].

A system for measuring optical fiber bandwidth utilizing the Pulse Spectrum Analysis method (PSA) has been established. This paper will discuss problems inherent to that system such as signal-to-noise ratio and off-peak error. Included are the results of bandwidth measurements for telecommunication grade fibers. Finally, the PSA method is compared to other bandwidth measurement methods.
[Contact: Robert L. Gallawa (303) 497-3761]

Shao, Y., and Gallawa, R.L., **A Comparison of Three Bandwidth Measurements Techniques for Optical Fibers.**

This paper presents the results of an experiment to compare three distinct methods or measuring the bandwidth of a telecommunication grade, multimode optical fiber. The three methods are 1) the time-domain method, 2) the frequency-domain method, and 3) the pulse spectrum analysis method. We find good agreement between the frequency-domain method and the pulse spectrum analysis method, but the time-domain method yields results that are lower than the other two for the cases we considered.
[Contact: Robert L. Gallawa (303) 497-3761]

Recently Published

Rodhe, P.M., **Intramodal Part of the Transfer Function for an Optical Fiber**, J. Lightwave Technology, Vol. LT-13, No. 1, pp. 154-158 (February 1985).

Intramodal contributions in measurements of optical fiber bandwidth are investigated theoretically and experimentally in the quasimonochromatic case. A relation is established between the intramodal transfer function and a possibly non-Gaussian source spectrum, which may also vary with modulation frequency. By considering the latter variation in particular, we are able to predict the intramodal length dependence and show how it may deviate from that of a conventional approach.
[Contact: Aaron A. Sanders (303) 497-5341]

Other Fast Signal Topics

Released for Publication

Gibson, K.A., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, to be published as NBSIR 85-3022.

This bibliography lists the publications of the personnel of the NBS Electromagnetic Fields Division in the period from January 1982 through December 1983.
[Contact: (303) 497-3132]

Hill, D.A., **Electromagnetic Wave Propagation in an Asymmetrical Coal Seam.**

Electromagnetic wave propagation in a coal seam is analyzed for the case where the surrounding floor and roof rocks have different electrical properties. Numerical results are presented for the attenuation rate and field distribution of the dominant mode. The results have application to mine communication and remote sensing of coal seams.
[Contact: (303) 497-3472]

Other Fast Signal Topics, cont'd.

Judish, R.M., **Quality Control of Measurements - Measurement Assurance,** to be published in the forthcoming special issue of the Proceedings of the IEEE on Radio Measurement Methods and Standards.

The ability to relate individual measurements to nationally accepted standards is a requirement of traceability. This paper discusses a perspective in which the goals of traceability are viewed in terms of performance requirements on the quality of measurements as reflected in a statement of uncertainty.
[Contact: (303) 497-3380]

Recently Published

Katzir, Y., Young, M., and Glaser, I., **Pattern Recognition Using Incoherent OTF Synthesis and Edge Enhancement,** Applied Optics, Vol. 24, No. 6, pp. 863-867 (15 March 1985).

This paper describes a system for pattern recognition using an incoherent-optical correlator. The system uses optical transfer function synthesis to perform correlations with an edge-enhanced image of the object or pattern being sought. The resulting correlations are free of bias and show good discrimination between objects. In addition, the difficult or time-consuming computations are performed before the operation of the system; this reduces the amount of postprocessing by computer and should allow real-time operation at video rates.
[Contact: Matt Young (303) 497-3223]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications,** NBSIR 85-3029 (July 1985).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1984. A few earlier references that are directly related to the present work of the Division are included.
[Contact: (303) 497-3678]

Major, J.R., Livingston, E.M., and Adair, R.T., **Automatic Frequency Response of Frequency-Modulated Generators Using the Bessel Null Method,** 24th ARFTG Conference Digest, Fall 1984, Columbia, MD, December 5-6, 1984, pp. 131-153 (1985). [An identical invited paper will be published in the Proceedings of the Test and Measurement World Expo, San Jose, California, May 13-15, 1985.]

This paper describes a Bessel null technique to measure the frequency response of a frequency-modulated rf carrier and a program to automate frequency response measurements of signal generators with output frequencies from 0.450 to 2000 MHz. The measurements obtained using this technique are more accurate than those obtained by a highly trained technician using a manual system.

Automated measurement of this process is desirable since the manual method is subject to the following problems: (1) excessive time, (2) error in finding the null, and (3) lack of assurance that the null is the first Bessel null. Automated measurements can be performed using a system controller, a spectrum analyzer, a function generator, and a voltmeter (all of which are compatible and controllable remotely).

The nonlinear relationship between modulating signal amplitude and the center frequency amplitude of the carrier is a major obstacle to automated measurement. This problem was solved by obtaining an approximate formula for this nonlinear curve.

Assurance that the null found is the first Bessel null is provided by the analysis of the frequency response of the signal generator under test as displayed on the spectrum analyzer.
[Contact: (303) 497-3149]

Microwave Metrology, cont'd.

port parameters without using additional standards. A computer simulation was performed assuming that the true power into each six-port detector is related to the power observed by the detector. Simultaneous estimation of the six-port and detector parameters is accomplished through a nonlinear least-squares algorithm. Results of the simulation compare the reflection coefficient Γ computed from corrected power readings and Γ calculated from observed power readings.
[Contact: (303) 497-3574]

Juroshek, J.R., and Hoer, C.A., **A Technique for Extending the Dynamic Range of the Dual Six-Port Network Analyzer,** IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-33, No. 6, pp. 453-459 (June 1985).

The dynamic range of the six-port type of automatic network analyzer is typically limited to measuring two-port devices with a transmission coefficient S_{12} in the range of 0 to -60 dB. This paper describes a subcarrier approach for extending the dynamic range of the dual six-port network analyzer. The subcarrier is generated by inserting a 10-kHz, biphase modulator ahead of one of the six ports. With the subcarrier approach, measurements of S_{12} in the range of -60 to -100 dB can be made. Test results are presented showing measurements of S_{12} = -80 dB with a precision of ±0.05 dB or better, and an accuracy of ±0.16 dB or better at 3 GHz. Measurement results are also presented showing the dynamic range achievable with thermistor and barretter detectors.
[Contact: (303) 497-5362]

Kanda, M., and Orr, R.D., **A Radio-Frequency Power Delivery System: Procedures for Error Analysis and Self-Calibration,** NBS Technical Note 1083 (August 1985).

An expression is developed for net power delivered to a load in terms of the indicated forward and reflected power and the system S-parameters and reflection coefficients. The directional coupler is treated as nonideal with power reflections assumed between all ports. The system itself is used to evaluate the major S-parameter terms in net power computation, and uncertainty in the computer power is derived from origins in the power meter readings and incompletely known S-parameters.
[Contact: (303) 497-5320]

Reeve, G.R., and Miller, C.K.S., **Current NBS Metrology Capabilities and Limitations at Millimeter Wave Frequencies,** Proceedings of the 1985 Measurement Science Conference, Santa Clara, California, January 17-18, 1985, pp. 296-314.

The National Bureau of Standards (NBS) establishes national artifact standards and provides a metrology base for U.S. industry and technology. In the millimeter wave frequency spectrum, NBS has not established all of the required metrology to meet the needs of industry or government for this technology. It is the intent of this paper to describe the technical demands of responding to the challenges of millimeter-wave technology. A description of the current capabilities that exist at NBS is given for those parameters and frequencies where measurement services exist. Where novel standards have been developed, such as the 94-GHz thermal noise standard, the physical basis for the standard is described to indicate the changes from lower frequency designs and the challenges that had to be overcome. Limitations in services and in concepts of standards for providing those services are described to indicate the degree of research that must be undertaken to satisfy future industrial needs in this evolving technology.
[Contact: (303) 497-3557]

Laser Metrology

Laser Metrology, cont'd.

Bennett, H.E., Milam, D., Guenther, A.H., and Newman, B.E., **Laser Induced Damage in Optical Materials: 1983**, to be published as NBS Special Publication 688.

The Fifteenth Annual Symposium on Optical Materials for High Power Lasers (Boulder Damage Symposium) was held at the National Bureau of Standards in Boulder, Colorado, November 14-16, 1983. The Symposium was held under the auspices of ASTM Committee F-1, Subcommittee on Laser Standards, with the joint sponsorship of NBS, The Defense Advanced Research Project Agency, the Department of Energy, the Office of Naval Research, and the Air Force Office of Scientific Research. Approximately 200 scientists attended the Symposium, including representatives of the United Kingdom, France, Israel, and West Germany. The Symposium was divided into sessions concerning Materials and Measurements, Mirrors and Surfaces, Thin Films, and Fundamental Mechanisms. As in previous years, the emphasis of the papers presented at the Symposium was directed toward new frontiers and new developments. Particular emphasis was given to materials for high power apparatus. The wavelength range of prime interest was from ~0.6 μm to the uv region. Highlights included surface characterization, thin film-substrate boundaries, and advances in fundamental laser-matter threshold interactions and mechanisms. The scaling of damage thresholds with pulse duration, focal area, and wavelength was discussed in detail. Harold E. Bennett of the Naval Weapons Center, Arthur H. Guenther of the Air Force Weapons Laboratory, David Milam of the Lawrence Livermore National Laboratory, and Brian E. Newman of the Los Alamos National Laboratory were co-chairmen of the Symposium.
[Contact: Aaron A. Sanders (303) 497-3535]

Franzen, D.L., and Kanada, T., **A Picosecond Light Source Tunable from 1.35 to 1.54 μm.**

A rhodamine-6G dye laser is synchronously pumped by a doubled, cw, mode-locked Nd:YAG laser. Pulses from the dye laser are mixed in a $LiIO_3$ crystal with 1.06-μm pulses from the pump to produce a difference frequency tunable from 1.35 to 1.54 μm. Average power, peak power, and pulse width were approximately 4 μW, 12 mW, and 3 to 4 ps, respectively. Improvements in performance are discussed.
[Contact: (303) 497-3346]

Optical Fiber Metrology

Released for Publication

Day, G.W., McFadden, J.D.O., Veeser, L.R., Chandler, G.I., and Cernosek, R.W., **Optical Fiber Sensors for the Measurement of Pulsed Electric Currents**, to be published in the Proceedings of the AGARD (NATO Advisory Group for Aerospace Research and Development) Specialists Meeting on Optical Guided Waves in the Military Environment, Istanbul, Turkey, September 23-27, 1985.

Recent progress in the design of fiber sensors for pulsed electric currents is reviewed. Several of the most useful sensor configurations are described and compared. Models are used to predict the transfer function of these sensors, their sensitivity to nonideal fiber properties, particularly linear birefringence, and methods for overcoming these problems. Other recent research is examined to suggest the prospect for sensors with improved sensitivity and stability.
[Contact: (303) 497-5204]

Maisonneuve, J.M., Churoux, P., and Gallawa, R.L., **Use of Mode Transfer Matrices in LAN Loss Evaluation**, to be published in Proc. SPIE - The International Society for Optical Engineering, 559 [Conference, San Diego, California, August 18-23, 1985].

Other Fast Signal Topics, cont'd.

Reeve, G.R., and Miller, C.K.S., **Current NBS Metrology Capabilities and Limitations at Millimeter Wave Frequencies,** Proceedings of the 1985 Measurement Science Conference, Santa Clara, California, January 17-18, 1985, pp. 296-314.

The National Bureau of Standards (NBS) establishes national artifact standards and provides a metrology base for U.S. industry and technology. In the millimeter wave frequency spectrum, NBS has not established all of the required metrology to meet the needs of industry or government for this technology. It is the intent of this paper to describe the technical demands of responding to the challenges of millimeter-wave technology. A description of the current capabilities that exist at NBS is given for those parameters and frequencies where measurement services exist. Where novel standards have been developed, such as the 94-GHz thermal noise standard, the physical basis for the standard is described to indicate the changes from lower frequency designs and the challenges that had to be overcome. Limitations in services and in concepts of standards for providing those services are described to indicate the degree of research that must be undertaken to satisfy future industrial needs in this evolving technology.
[Contact: (303) 497-3557]

Young, M., and Johnson, E.G., Jr., **Redefining the Scratch Standards**, NBS Technical Note 1080 (February 1985). [Some of this material was presented in a paper, Tunable Scratch Standards, given at the conference of the International Society for Optical Engineering, Measurement and Effects of Surface Defects and Quality of Polish, Los Angeles, CA, January 21-22, 1985, and published in Proc. SPIE, Vol. 525, pp. 70-77, SPIE, P.O. Box 20, Bellingham, WA 98227 (1985).]

The scratch standard (MIL-O-13830A) is a cosmetic standard that is effected by a visual comparison with a set of submasters that are in turn evaluated by comparison with a set of master standards. Both manufacture and certification of the submasters are somewhat unreliable. In this paper, we show that the submasters can be classified according to the relative power scattered at a relatively small angle. We have designed etched gratings with which to replace the submasters; these gratings have the appearance of scratches but diffract light into a broad peak between 5 and 10 degrees off the axis of the incident beam. We have classified some prototypes both by comparison with the master standards and by a photoelectric measurement; agreement between the two methods is good. We suggest that such gratings be used as the submasters and possibly that they be classified by a photoelectric, rather than visual, measurement.
[Contact: (303) 497-3223]

Young, M., **Scratch Standards Should not be Used to Predict Damage Threshold** in Laser Induced Damage in Optical Materials: 1982, Proceedings of a Symposium, H.E. Bennett, A.H. Guenther, D. Milam, and B.E. Newman, Eds., NBS Special Publication 669 (January 1984).

The scratch and dig standards are the most widely used surface quality standards in the industry. In the Proceedings of the 1980 Symposium, H. Bennett showed theoretically that damage ought to be initiated near a defect and related damage threshold to defect size. Evidently, because of one or both of these considerations, some purchasers may use the scratch standards to specify the surface quality of components intended for high power laser systems. Although damage is often associated with the presence of a defect, this is an inappropriate use of these purely cosmetic standards; the classification of a particular scratch correlates only very loosely with its width or depth. Even if a component is made of glass, little or nothing pertinent to damage threshold

Other Fast Signal Topics, cont'd.

may be determined by classifying a scratch according to the cosmetic standard.
[Contact: (303) 497-3223]

Young, M., **The Scratch Standard Is Not a Performance Standard,** Proceedings of the Optical Fabrication and Testing Workshop, Cherry Hill, New Jersey, June 12-13, 1985, pp. ThAA4-1 and 2.

A history and description of the scratch standard is presented, showing that the scratch number should never be related to its width and that the standard is cosmetic only.
[Contact: (303) 497-3223]

Young, M., **The Scratch Standard Is Only a Cosmetic Standard,** Laser Focus/Electro-Optics.

A history of the scratch and dig standard is presented, describing its application and pointing out that it may not be used for quantitative assessments such as width measurement.
[Contact: (303) 497-3223]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

FitzPatrick, G.J., Forster, E.O., Kelley, E.F., and Hebner, R.E., **Streamer Initiation in Liquid Hydrocarbons,** to be published in the Conference Record, 1985 Conference on Electrical Insulation and Dielectric Phenomena, Buffalo, New York, October 21-24, 1985.

Using 93X magnification and a framing rate of 2×10^7 frames/s, the initiation of prebreakdown streamers in toluene, isooctane, and a white oil have been photographed. The initial growth from a negative point electrode was a thin pencil-like structure, having a growth rate of 2 to 3 $\times 10^4$ cm/s, which subsequently branched into a tree-like structure. Positive streamers were found to develop into a more filamentary structure than negative streamers. Under nominally identical conditions, a positive streamer may grow, then disappear; may grow to bridge the gap; or may grow to a certain length, then persist.
[Contact: (301) 921-3121]

McKnight, R.H., **Measurement of Electric Field and Ion-Related Quantities,** to be published as a chapter in the CRC Handbook on Air Ions.

Measurements of various quantities to describe the electrical characteristics of the atmosphere have been made for many decades by atmospheric scientists using a variety of instruments and measurement techniques. This chapter describes, with text and figures, those techniques which have application in present day ion-related research. Topics covered include definitions of terms; measurements of electric field, space potential, vertical current density, conductivity, net space-charge density, unipolar ion density, and ion mobility; species identification; errors associated with external electric fields and off-ground operation of instruments, and applications of measurements (23 figures, 101 literature references).
[Contact: (301) 921-3121]

Van Brunt, R.J., **Water Vapor-Enhanced Electron Avalanche Growth in SF_6 for Nonuniform Fields.**

When trace water vapor content is increased from 10 to 100 parts per million by volume in SF_6 at pressures from 200 to 300 kPa, a dramatic enhancement occurs in the mean size of electron avalanches formed near a positive point electrode. Although this effect can be attributed to a change in gas composition, it is not due to a change in the ionization rate for the gas. It is proposed that the avalanche enhancement is due primarily to an increase in the probability for initiating electron

Power Systems Metrology, cont'd.

release from minor negative ions associated with water vapor that collisionally detach more readily at a given field strength than the predominant negative ions associated with SF_6. The profiles of the electron avalanche size distributions exhibit a monotonic decrease of probability with increasing number of electrons for avalanches with fewer than 10^7 electrons, but pronounced peaks appear in the distributions as the mean electron number exceeds 10^7. These peaks are not consistent with the behavior expected from a stochastic model of electron avalanche growth in nonuniform electric fields which neglects the influence of space charge.
[Contact: (301) 921-3121]

Recently Published

Misakian, M., **High Voltage Divider and Resistor Calibrations,** NBS Technical Note 1215 (July 1985).

An NBS calibration service for determining the ratio of high voltage dc dividers and the resistance of high voltage resistors is described. Calibrations are performed with a Wheatstone bridge apparatus with a simple guard system. Sources of systematic error are identified and methods for characterizing the NBS standard high voltage resistors are discussed. Ratio and resistance values can be determined between the voltages of 10 kV and 150 kV with an uncertainty of less than ±0.01%.
[Contact: (301) 921-3121]

Petersons, O., and Mehta, S.P., **Calibration of Test Systems for Measuring Power Losses of Transformers,** NBS Technical Note 1204 (August 1985).

A calibration system for accuracy verification and alignment of test systems for measuring transformer losses is described. Methodologies are presented for assessing measurement uncertainties and for evaluating overall accuracy of test systems. Procedures are suggested for continuing maintenance and calibration of standard instruments and test systems to ensure traceable measurements.
[Contact: (301) 921-2328]

Ramboz, J.D., and Petersons, O., **Emerging New Requirements for Electric Power and Energy Measurements,** Proceedings of the 1985 Workshop and Symposium of the National Conference of Standards Laboratories, Boulder, Colorado, July 15-18, 1985, pp. 3-12.

Advances in electronic instrumentation technology have brought greater stability and precision to transducers that are utilized for measuring electric power and energy. An advantage of instruments based on electronic transducers is that they can be readily adapted to the measurement of other quantities such as current, voltage, reactive and apparent power, power factor, demand, time-of-day readings, etc. The increases in the cost of energy during the past decade have stimulated the acceptance of new instrument technology by the users associated with the electric power industry. The electronic instruments have especially found acceptance in metering installations for large loads and at interchange points between utilities. Modern instruments, because of their accuracy capabilities, are also advantageous in those applications where the efficiency of large equipment such as generators and transformers has to be measured. A large number of instruments used as physical standards by the industry and submitted recently to the National Bureau of Standards (NBS) for calibration have been of the electronic type. The calibration accuracies requested from NBS for power and energy measurements have increased at least fivefold (uncertainty reduction from ±0.05% to ±0.01%) within the past several years. Calibrations for different quantities and values are being requested. These changing calibration requirements and the response of NBS to meet the requests of its calibration clientele are discussed.
[Contact: (301) 921-3121]

Power Systems Metrology, cont'd.

Schwitz, W., Kampfer, R., Braun, A., Souders, T.M., Moore, W.J.M., Cassidy, B.R., and Deacon, T.A., **International Comparison of Current Transformer Calibrations**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-34, No. 2, pp. 234-238 (June 1985).

An international comparison of current transformer calibrations among five metrology laboratories has been conducted. The measurements were made at current ratios ranging from 1 A:1 A to 200 A:1 A at 10, 100, and 200 percent of rated current and from 5 A:5 A to 200 A:5 A at 1, 10, 100, and 200 percent of rated current, at a frequency of 50 Hz. Several ratios have also been compared at 60 Hz.
[Contact: T. Michael Souders (301) 921-2727]

Siddagangappa, M.C., and Van Brunt, R.J., **Decomposition Products from Corona in SF_6/N_2 and SF_6/O_2 Mixtures**, Proceedings of the Eighth International Conference on Gas Discharges and Their Applications, Oxford, England, September 16-20, 1985, pp. 247-250.

Absolute concentrations of SOF_4, SOF_2, SO_2F_2, SO_2, NO, N_2O, and H_2O produced from continuous, dc, point-plane negative corona at a current of 40 A were measured in SF_6/N_2 and SF_6/O_2 mixtures containing trace amounts of H_2O and 1 to 95% N_2 or 1 to 10% O_2 for a total gas pressure of 200 kPa (~2 atm). The absolute and SF_6-normalized charge rates-of-production for these by-products have been determined as a function of N_2 or O_2 content. The results are interpreted in terms of a model for electric-discharge-induced decomposition of SF_6 discussed previously by Van Brunt. The presence of N_2 accelerates the rate of SF_6 decomposition by inhibiting the recombination of SF_6 dissociation products. At levels up to 10%, O_2 actually lowers the rates of oxyfluoride and SO_2 production due to its effect in reducing the mean energy of electrons in the discharge and thus the dissociation rate of SF_6.
[Contact: Richard J. Van Brunt (301) 921-3121]

Pulse Power Metrology

Released for Publication

Hebner, R.E., **High-Speed Data Systems for Pulsed Power Applications**, to be published in the Proceedings of the 5th IEEE Pulsed Power Conference, Washington, DC, June 10-12, 1985.

Data acquisition systems for pulse power applications generally must provide nanosecond resolution, operate in an environment of high levels of electromagnetic interference, and acquire significant amounts of data simultaneously. To meet these demands, electrical systems have been used and optical systems are being introduced. Voluntary standards have been and are being developed which categorize the errors in the electrical measurement systems. Optical systems are in too early a state of development for similar standardization.
[Contact: (301) 921-3121]

Superconductors

Released for Publication

Dube, W.P., and Goodrich, L.F., **A Quench Detector Design for Superconductor Testing.**

A quench detector is a device that interrupts the flow of current through a superconductor in the event the superconductor reverts to the normal, resistive state. This new design has adjustable filtering and sensitivity. The input is well isolated from the output, eliminating any possible ground loop through the detector. It also has excellent noise immunity.
[Contact: Loren F. Goodrich (303) 497-3143]

Superconductors, cont'd.

Fickett, F.R., and Capobianco, T.E., **Relationships Between Mechanical and Magnetoelectric Properties of Oxygen-Free Copper at 4 K.**

Commercially pure, oxygen-free copper is the material of choice for nearly all superconductor stabilization. It is well known that straining relatively pure copper at 4 K can result in significant increases in the residual resistivity and, thus, a decreased ability of the copper to stabilize the superconductor. In this paper we quantify the effect of strain on the resistivity and magnetoresistivity of a large number of oxygen-free coppers from various sources and in various tempers and states of reanneal. In addition, the detailed low-temperature stress-strain behavior of these materials and its correlation with room temperature data and the residual resistivity ratio (RRR) prior to straining will be reported. An apparatus developed for mechanical properties testing of relatively small wire samples at low temperature will be described.
[Contact: (303) 497-3785]

Goldfarb, R.B., and Clark, A.F., **AC Losses in Nb-Ti Measured by Magnetization and Complex Susceptibility.**

DC magnetization and complex AC susceptibility were measured at 4 K as functions of longitudinal DC field for a multifilamentary Nb-Ti superconductor with no transport current. Minor hysteresis loops were obtained in the dc measurements. The full-penetration field H_p, a function of applied field H, was deduced directly for each minor loop. The values for H_p were fit to the Kim-type equation, $H_p(H) = H_p(0)/(1+H/H_k)$, where $H_p(0)$ and H_k are constants. The minor-hysteresis-loop areas gave losses that were in excellent agreement with Carr's theoretical critical-state equation, $W = (4\mu_0 H_0 H_p/3)(1-H_p/2H_0)$, where H_0 is the maximum applied field for each loop.

An expression was obtained for the ideal reversible differential susceptibility, $\chi_{rev} = \phi_0/8\pi\mu_0(H-H_{c1})\lambda^2$, where ϕ_0 is the flux quantum, H_{c1} is the lower critical field, and λ is the penetration depth. H_{c1} and λ for the sample were deduced from the shape of the major hysteresis loop. Clem's theoretical expressions for the real (χ') and imaginary (χ'') components of AC susceptibility are functions of AC field amplitude h, H_p, and χ_{rev}. The predicted susceptibilities based on these expressions were in good agreement with measured curves of χ' and χ'' as functions of h and H. The measured χ' and χ'' were independent of frequency up to 1 kHz, as expected when bulk hysteresis is the primary loss mechanism.
[Contact: (303) 497-3650]

Goodrich, L.F., Dube, W.P., Pittman, E.S., and Clark, A.F., **The Effect of Aspect Ratio on Critical Current in Multifilamentary Superconductors.**

Experimental data and discussion are presented on the critical current of straight superconductors as a function of the orientation of a perpendicular applied magnetic field. Commercial, multifilamentary NbTi and Nb_3Sn samples were measured in a radial access magnet that allowed an arbitrary angle setting. The change in critical current was measured at different magnetic fields to scale the effect for use in a standard test method. For a NbTi sample, the critical current with the magnetic field parallel to the wider face of the conductor is higher than that with the perpendicular orientation. The effect can be as high as 40% for a NbTi sample with an aspect ratio of 6. The effect in Nb_3Sn is opposite that in NbTi. A discussion of the most likely cause of the effect, which accounts for the difference between NbTi and Nb_3Sn, is given.
[Contact: Clark (303) 497-3253]

Moreland, J., Ekin, J.W., and Goodrich, L.F., **Electron Tunneling into Superconducting Filaments: Depth Profiling**

Superconductors, cont'd.

the Energy Gap of NbTi Filaments in High-Field Magnet Wires, to be published in the Proceedings of the International Cryogenic Materials Conference in Advances in Cryogenic Engineering - Materials, Vol. 32, Boston, Massachusetts, August 12-16, 1985.

Squeezable electron tunneling (SET) junctions consisting of superconducting NbTi filaments (extracted from magnet wires) and sputtered Nb thin-film counter electrodes were used to determine the energy gap at the surface of the filaments. The current versus voltage curves of junctions immersed in liquid helium at 4 K were measured for a series of filaments taken from the same wire. Each filament had been etched to remove a surface layer of varying thickness so that the energy gap could be determined as a function of depth into the surface of an average filament. It was found that some manufacturing processes yield filaments having surface layers with reduced energy gaps of 0.4 meV compared to measured interior bulk values ranging from 1.2 to 1.3 meV.
[Contact: (303) 497-3641]

Recently Published

Ekin, J.W., Yamashita, T., and Hamasaki, K., **Effect of Uniaxial Strain on the Critical Current and Critical Field of Chevrel Phase $PbMo_6S_8$ Superconductors,** IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 474-477 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

The first measurements of the effect of uniaxial strain on the critical current of a Chevrel-phase superconductor, $PbMo_6S_8$, have been obtained at 4.2 K in magnetic fields from 2 T to 24 T. The data show there is a very significant reversible effect of elastic strain on the critical current of $PbMo_6S_8$, comparable in magnitude to that observed in Nb_3Sn. This is because both the peak pinning force and upper critical field are very sensitive to elastic strain. A correlation is noted between the elastic strain effect, radiation sensitivity, and crystal phase.
[Contact: (303) 497-5448]

Hong, M., Maher, D.M., Ellington, M.B., Hellman, F., Geballe, T.H., Ekin, J.W., and Holthuis, J.T., **Further Investigations of the Solid-Liquid Reaction and High-Field Critical Current Density in Liquid-Infiltrated Nb-Sn Superconductors,** IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 771-774 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

Superior superconducting properties, such as high critical current density (J_c) and transition temperature (T_c), have been obtained from reacted liquid-infiltrated Nb-Sn composite wires. These excellent properties are attributed to the chemistry and structure of the material which is prepared by a unique solid (Nb)-liquid (Sn) reaction. From heat capacity measurements, sharp bulk superconducting transitions of the A15 phase occur at 17.2-18 K and the weight fraction of A15 in the composite wire is ~23%. Analytical electron microscopy techniques have shown that: the microstructure of these conductors consists of alternating large- grain and small-grain filaments; these two types of filaments correspond to BCC Nb(Sn) and cubic A15 $Nb_{75\pm x}Sn_{25\mp x}$ phases, respectively; the A15 filaments (<0.5 μm) are chemically homogeneous in terms of measured x-ray intensity ratios to within ±7% which implies that x ~ 1.5; and the A15 grains are essentially free of extended lattice disorder down to a resolution of ~0.34 nm.

Recent work in which Nb is alloyed with Ta has shown that these superconducting properties can be improved upon; e.g., high overall J_c's of ~1.8×10^4 A/cm^2 at 20 T and 4.2 K have been measured.

Superconductors, cont'd.

Also, the liquid-infiltrated Nb(Ta)-Sn composites have a damage strain tolerance nearly double that of commercial bronze-processed Nb-Sn conductors.
[Contact: John W. Ekin (303) 497-5448]

Magnetic Materials and Measurements

Released for Publication

Capobianco, T.E., Fickett, F.R., and Moulder, J.C., **Mapping Eddy Current Probe Fields**, to be published in the Proceedings of the Review of Progress in Quantitative Nondestructive Evaluation, Vol. 5.

The magnetic fields produced by four different eddy current probes were mapped in the near field with very small (0.43-mm-diameter) inductive magnetic field sensors. The four eddy current probes included two nominally identical, absolute, air core probes; an absolute ferrite core probe; and a reflection probe with an air core excitation coil and two counterwound ferrite core pickup coils. Measured fields for the air core probes are compared with values calculated from the theory of Dodd and Deeds. All measurements were performed at 10 kHz; for the ferrite core probe, the field intensity was also measured from 1 kHz to 100 kHz using conventional methods.
[Contact: (303) 497-3641]

Recently Published

Cromar, M.W., Clark, A.F., and Fickett, F.R., **The NBS Magnetic Monopole Detector**, IEEE Transactions on Magnetics, Vol. MAG-21, No. 2, pp. 418-420 (March 1985). [Proceedings of Applied Superconductivity Conference, San Diego, California, September 9-13, 1984]

We have built and operated several inductive type monopole detectors, the present one having three concentric, orthogonal loops operated in coincidence. The area of each loop is 200 cm^2, and the cross-sectional area of the superconducting shield is 700 cm^2. The detector loops are in a trapped magnetic field of approximately 3 milligauss. The system is mechanically stable and is relatively insensitive to external disturbances, both mechanical and electromagnetic. The detector is quiet, having a signal-to-noise ratio for monopole detection of approximately 20. We have also investigated several sources of noise and spurious signals which might mimic a monopole event.
[Contact: (303) 497-5375]

Other Electrical Systems Topics

Released for Publication

Duffield, C.L., Moreland, J., and Fickett, F.R., **Cryogenic Operation of Bimorphs.**

Piezoelectric bimorphs constructed from lead titanate-zirconate (PZT) ceramic bonded to a brass sheet have been tested at cryogenic temperatures to determine their suitability for use in a low-temperature micropositioner. Experimental data are presented on bimorph sensitivity (displacement per volt) as a function of the number of temperature cycles. Results indicate that bimorphs of this type cannot be calibrated because of irreversible changes in the bending characteristics that occur while cycling from room temperature to 4 K.
[Contact: John Moreland (303) 497-3641]

ELECTROMAGNETIC INTERFERENCE

Released for Publication

Adams, J.W., and Vanzura, E.J., **Shielding Effectiveness Measurements of Plastics.**

Measurement of shielding effectiveness of plastic materials may give serious problems due to the insulating nature of many plastics. A method of making these measurements using a flanged coaxial

Electromagnetic Interference, cont'd.

holder overcomes these limitations.
[Contact: (303) 497-3328]

Crawford, M.L., and Koepke, G.H., **Comparing EM Susceptibility Measurement Results Between Reverberation and Anechoic Chambers**, to be published in the Proceedings of the 1985 IEEE International Symposium on Electromagnetic Compatibility, Wakefield, Massachusetts, August 20-22, 1985.

This paper contains measurement results obtained using a 2.74m × 3.1m × 4.6m reverberation chamber and a 4.9m × 6.7m × 8.5m anechoic chamber to determine the susceptibility of equipment under test (EUT) to incident electromagnetic radiation. The frequency range was 200 MHz to 18 GHz. The "correlation factor" between the two techniques appears to be directly proportional to the gain of the EUT. Four sample EUTs included in this study were a 1-cm dipole probe, a ridged horn antenna, a small rectangular transverse electromagnetic (TEM) transmission cell with an aperture, and a modified 2.75-in. diameter folded-fin aircraft rocket.
[Contact: (303) 497-5497]

Cruz, J.E., Driver, L.D., and Kanda, M., **Design of the National Bureau of Standards Isotropic Magnetic Field Meter (MFM-10) 300 kHz to 100 MHz**, to be published as NBS Technical Note 1085.

A broadband magnetic field meter has been developed at the National Bureau of Standards (NBS) for the frequency range of 300 kHz to 100 MHz. The isotropic antenna unit consists of three mutually orthogonal loops, each 10 cm in diameter. The magnetic field probe described in this paper has a measurement range of 0.1 to 30 A/m. The readout of the meter is in terms of the Hermitian or "total" magnitude of the magnetic field strength which is equal to the root-sum-square value of the three perpendicular magnetic field components at the measurement point. This magnetic field meter has nearly perfect isotropy over its dynamic range.

The electronic circuitry of the meter obtains the total magnitude of all field polarizations and all signals in the entire frequency band. The sensor is isotropic and is well suited for measuring the near field of an emitter, including regions of multiple reflections and standing waves. The meter can be used to monitor either the weak plane wave fields in the far zone of a transmitter or the complicated fields very close to a radiofrequency leakage source. The features described in this paper are: electronic design, physical construction, alignment and adjustment of the meter, and design considerations.
[Contact: (303) 497-3763]

Gibson, K.A., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, to be published as NBSIR 85-3022.

This bibliography lists the publications of the personnel of the NBS Electromagnetic Fields Division in the period from January 1982 through December 1983.
[Contact: (303) 497-3132]

Kanda, M., Larsen, E.B., Bosero, M., Galliano, P.G., Yokoshima, I., and Nahman, N.S., **Standards for Electromagnetic Field Measurements**, to be published in the forthcoming Special Issue of the Proceedings of the IEEE on Radio Measurement Methods and Standards.

This paper describes the methodology for standard electromagnetic field measurements using anechoic chambers, open-sites, guided wave structures, and probes as transfer standards.
[Contact: (303) 497-5320]

Phelan, R.J., Jr., Larson, D.R., and Simpson, P.A., **A Sensitive, High Frequency, Electromagnetic Field Probe Using a Semiconductor Laser in a Small**

Electromagnetic Interference, cont'd.

Loop Antenna, to be published in Proc. SPIE - The International Society for Optical Engineering, 559 [Conference, San Diego, CA, August 18-23, 1985].

Using a loop antenna in series with a semiconductor laser, an optically coupled electromagnetic field probe has demonstrated sensitivities better than 1 $\mu V/m/Hz^{1/2}$. The probe outside dimensions are equal to 5.7 × 5.7 × 1.3 cm^3. It can be used to measure frequencies as high as 2 GHz. The dynamic range is estimated to exceed 6 orders of magnitude for incident microwave powers.
[Contact: (303) 497-3696]

Randa, J., **A Lattice-Action Approach to Complex Electromagnetic Environments.**

We present an approach to measurements of complex electromagnetic environments based on the numerical minimization of the electromagnetic action functional on a lattice in Euclidean space time. The technique allows one to determine the minimum power density consistent with a few measurements of the electric or magnetic field within a given volume. Knowledge of the external sources irradiating the volume is not required.
[Contact: (303) 497-3150]

Wilson, P.F., and Ma, M.T., **Factors Influencing Material Shielding Effectiveness Measurements,** to be published in the Proceedings of the IEEE 1985 International Symposium on Electromagnetic Compatibility, Wakefield, Massachusetts, August 20-22, 1985.

A material's shielding effectiveness is often measured in terms of insertion loss, that is, the field reduction between a transmitter and receiver achieved by introducing the shield material. The insertion loss concept is simply stated; however, ambiguities arise when one attempts to interpret specific insertion loss measurements. Insertion loss data depend not only on the shield material tested, but also on the measurement procedure. The antenna types used and their positioning, the incident waveform and its wave impedance, and the contact resistance between the test material and its mount (if any) can all affect insertion loss measurements, sometimes dramatically. These concepts are discussed based on the simple model of coupling through an electrically small aperture, loaded and unloaded, with the shield material. Emphasis is on the importance of understanding and recognizing these factors when making or interpreting the results of shielding effectiveness measurements.
[Contact: (303) 497-3842]

Wilson, P.F., and Ma, M.T., **Simple, Approximate Expressions for Higher-Order Modes and Resonances in TEM Cells.**

Simple, approximate expressions for determining the cutoff frequencies of the first few higher-order modes and the associated resonances in TEM cells are presented. Both symmetric and asymmetric cells are discussed with examples.
[Contact: (303) 497-3842]

Recently Published

Bensema, W.D., Reeve, G., and Koepke, G.F., **A Multisensor Automated EM Field Measurement System,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 200-202.

A system is being developed to monitor and collect electromagnetic (EM) field strength at multiple locations simultaneously. The system has two modes of operation: (1) for sampling EM fields that are stationary for times of the order of 200 ms, and (2) for sampling changing EM fields with a system resolution of 10 μs. Sensing elements for Mode 1 consist of three electrically

Electromagnetic Interference, cont'd.

short orthogonal dipoles mounted together, single dipole elements, or small loop antennas. Each element feeds a separate data input channel for a maximum of 30 channels. Rf energy is converted to dc by a small diode detector at each dipole. Several sets of 30 sensing elements each are planned to cover specific measurement regions of amplitude (1 V/m or greater) and frequency (100 MHz-18 GHz). Mode 2 sensors are diode detectors driven by broadband antennas. System computer data processing proceeds in real time and includes calculation of field strength based on probe calibrations and processing of resultant data to satisfy measurement goals.
[Contact: (303) 497-3465]

Cruz, J.E., and Larsen, E.B., **Screenroom Measurements of Antenna Factors,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, p. 208.

The measurement of electromagnetic fields in a shielded enclosure (screenroom) has serious problems because of uncertain antenna factors and multipath reflections from conductive surfaces. Most electromagnetic interference antennas at NBS are calibrated in a known field at an open-field site using the standard antenna method. Because these antenna factors are not necessarily applicable for making measurements in a screenroom, the measurement errors are difficult to determine. This paper presents the results for antenna factors determined in a screenroom using the two-antenna method. These antenna factors are compared with antenna factors determined at an open-field site and in an anechoic chamber. Experiment data are presented to show the variability of antenna factor as a function of frequency and location in the screenroom, thereby providing an indication of error bounds.
[Contact: (303) 497-3763]

Hill, D.A., and Koepke, G.H., **A Near-Field Array of Yagi-Uda Antennas for Electromagnetic Susceptibility Testing,** NBS Technical Note 1082 (July 1985).

In electromagnetic susceptibility testing of electronic equipment, the ideal incident field is a plane wave. To approximate this condition, a seven-element array of Yagi-Uda antennas has been constructed and tested at a frequency of 500 MHz. The element weightings are determined by a near-field synthesis technique which optimizes the uniformity of the field throughout a rectangular test volume in the near field of the array. The amplitude and phase of the electric field has been measured throughout the test volume with a short dipole probe, and the agreement with the theory is excellent.
[Contact: (303) 497-3472]

Kanda, M., and Nahman, N.S., **Standards for Measurement of Electromagnetic Fields,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 20-23.

The standards developed at NBS for measurements of electromagnetic fields are reviewed along with the industrial applications that engendered their development. Some attention is given to future measurement requirements and the NBS programs to meet them.
[Contact: (303) 497-5320]

Kanda, M., Randa, J., and Nahman, N.S., **Possible Estimation Methodologies for Electromagnetic Field Distributions in Complex Environments,** NBS Technical Note 1081 (March 1985).

The problem of measuring and characterizing complicated multiple-source, multiple-frequency electromagnetic environments is becoming more important and more difficult as electrical devices proliferate. This paper outlines three general approaches to the problem which are currently under investigation at the

Electromagnetic Interference, cont'd.

National Bureau of Standards. The three approaches are: (1) a statistical treatment of the spatial distribution of electromagnetic field intensities, (2) a numerical computation using a finite-difference (or lattice) form of the electromagnetic action functional, and (3) use of a directional probe to scan a volume. All three methods are still in the development stage, but each appears promising.
[Contact: (303) 497-5320]

Larsen, E.B., and Cruz, J.E., **E and H Fields in Transmission Lines and Coils for Susceptibility Testing, Probe Calibration, and RF Exposure Chambers,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, p. 199.

This paper deals with the instrumentation and design equations for several systems used to generate calculable electric (E) and magnetic (H) fields for electromagnetic compatibility (EMC) testing. These "standard" electromagnetic (EM) fields with known magnitude are used to: (a) test the susceptibility of electronic equipment to radiated fields, (b) calibrate E and H field probes for measuring and mapping fields, and (c) expose biological specimens in a known EM environment. The design and use of so-called transverse electromagnetic (TEM) cells terminated in their characteristic impedance are described elsewhere.
[Contact: (303) 497-3540]

Ma, M.T., Kanda, M., Crawford, M.L., and Larsen, E.B., **A Review of Electromagnetic Compatibility/Interference Measurement Methodologies,** Proceedings of the IEEE, Vol. 73, No. 3, pp. 388-411 (March 1985).

This paper presents a review summary of radiated emission and susceptibility measurement methodologies currently used for assessing the electromagnetic compatibility/interference (EMC/EMI) characteristics of electronic devices and systems. In particular, measurement methods using open sites, transverse electromagnetic (TEM) cells, reverberating chambers, and anechoic chambers are discussed, in the light of their technical justifications and bases, their strengths and limitations, and interpretation of the measurement results.
[Contact: (303) 497-3800]

Wilson, P.F., and Ma, M.T., **Shielding-Effectiveness Measurements with a Dual TEM Cell,** IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-27, No. 3, pp. 137-142 (August 1985).

Small-aperture theory is used to investigate the dual transverse electromagnetic (TEM) cell. Analyzing coupling through an empty aperture versus a loaded aperture leads to a simple model of dual-TEM-cell material shielding-effectiveness (SE) measurements. Experimental data are compared to theory with good agreement in the case of an empty aperture. Some of the difficulties in analyzing a loaded aperture are discussed.
[Contact: (303) 497-3842]

1986 CEEE Calendar

22-23 April (Gaithersburg, MD)

Workshop on Test Procedures for Precision Instrumentation and ATE Systems. This Workshop is intended to provide a forum for the exchange of information among researchers, users, manufacturers, testing companies, and calibration laboratories on the procedures used in testing the performance of precision instrumentation and automatic test equipment systems. Technical topics planned include first-article and acceptance testing, bid-sample testing, maintenance and calibration testing, developing and writing specifications and procedures, "minimum-use" specifications, test accuracy ratios, economic tradeoffs of testing, case histories of

1986 CEEE Calendar, cont'd.

specific test programs, optimum calibration strategies, and recommended practices. The Workshop proceedings will be published by the Institute of Electrical and Electronics Engineers.
[Contact: John R. Sorrells, (301) 921-2727]

23-27 June (Gaithersburg, MD)

1986 CPEM (Conference on Precision Electromagnetic Measurements). CPEM 86 is being sponsored by the U.S. National Bureau of Standards, the IEEE Instrumentation and Measurement Society, and the Union Radio Scientifique Internationale. The Conference will present papers covering the theory, design, performance, simulation, and application of electromagnetic standards, measurements, techniques, instruments, and systems. Sessions are tentatively planned to cover the following technical areas: electromagnetic-related fundamental constants and standards; direct current, low frequency, and radiofrequency; time, time interval, and frequency; antennas and fields; microwaves and millimeter waves; infrared, visible, and ultraviolet radiation; lasers; electro-optics and fiber optics; cryoelectronics; automated measurements; and technical calibration services. The Conference language will be English. [Contact: Sara Torrence, (301) 921-2721. (For technical information, contact John R. Sorrells, (301) 921-2727 or Norman B. Belecki, (301) 921-2715.)]

9-10 September (Boulder, CO)

Symposium on Optical Fiber Measurements. This fourth biennial Symposium is devoted to measurements on optical fiber, related components, and systems. It is sponsored by NBS in cooperation with the IEEE Optical Communications Committee and the Optical Society of America and is intended to provide a forum for reporting the results of recent measurements research and for evaluating these results in terms of future directions. About one-quarter of the sessions will be workshops led by invited panelists. Summaries of presented papers will be published in a technical digest to be distributed at the Symposium.
[Contact: Susie A. Rivera, (303) 497-5342]

RECENTLY ISSUED STANDARD REFERENCE MATERIALS

The first practical superconducting standard reference material (SRM) has been released by the Electromagnetic Technology Division to the NBS Office of Standard Reference Materials for sale to the public. The certified parameter of SRM 1457, Superconducting Critical Current -- NbTi Wire, is critical current at magnetic fields of 2,4,6, and 8 tesla at a temperature of 4.2 K and an electric field criterion of 0.2 μV/cm. Information is given to permit the user to determine critical current for temperatures in the range 3.90 to 4.24 K and electric field criteria from 0.05 to 0.2 μV/cm.

SRM 1457 consists of a 2.2-m length of a multifilimentary, niobium-titanium, copper-stabilized wire, wound in a single layer on a spool having a core diameter of 8.7 cm. The wire is evaluated for 34 parameters relating to current, voltage, magnetic field, temperature, strain, and physical specimen characteristics.

In conjunction with ASTM Standard Test Method B714-82, D-C Critical Current of Composite Superconductors, the new SRM is intended to provide means for calibrating apparatus used to measure key parameters of superconductor products and thus should be useful to buyers and sellers of superconductors, users of superconducting equipment, and researchers in superconducting technology.

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All technical information included in this document has been previously approved for publication.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

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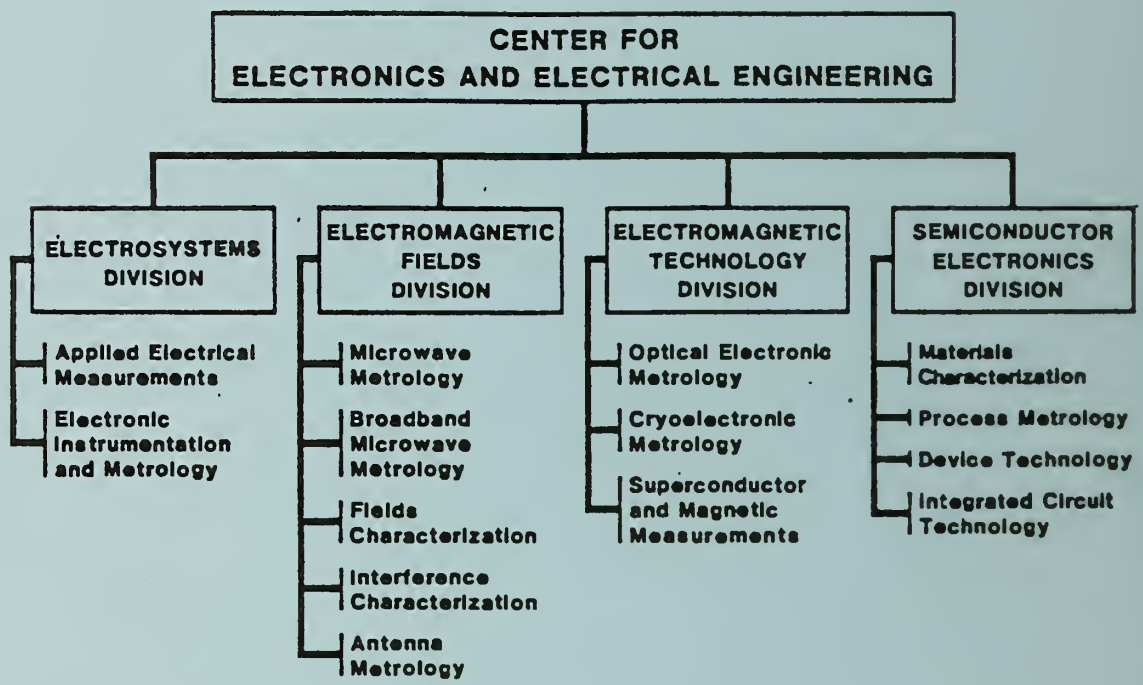

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